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*M. P. Shannon
K. A. Jacobs
L. R. Ramirez
D. A. Arnall
A. M. Woolf
R. D. Hagan
J. A. Hodgdon
B. L. Bennett*

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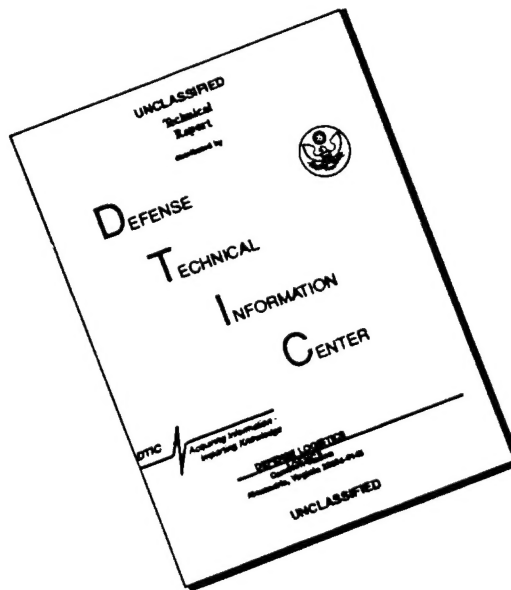


NAVAL HEALTH RESEARCH CENTER
P. O. BOX 85122
SAN DIEGO, CALIFORNIA 92186 - 5122

NAVAL MEDICAL RESEARCH AND DEVELOPMENT COMMAND
BETHESDA, MARYLAND



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**COMPARISON OF ANTI-EXPOSURE SUITS
DURING REST AND ARM EXERCISE IN COLD WATER**

M.P. Shannon, B.S.¹

K.A. Jacobs, M.A.¹

LT L.R. Ramirez, MSC, USNR²

D.A. Arnall, Ph.D.³

LT A.M. Woolf, MC, USN²

R.D. Hagan, Ph.D.¹

J.A. Hodgdon, Ph.D.²

CDR B.L. Bennett, MSC, USN²

¹GEO-CENTERS, Inc.
Ft. Washington, MD 20744

²Naval Health Research Center
P.O. Box 85122
San Diego, CA 92186-5122

³Department of Physical Therapy
University of Northern Arizona
Flagstaff, AR 86004

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SUMMARY

Problem.

Damage control personnel normally perform shipboard flooding operations dressed in dungarees or engineering coveralls. However, these garments may be inadequate for this purpose because they are not designed for cold-water exposure. Thus, the identification of protective ensembles for use in cold-water flooding operations is of interest to naval personnel.

Objective.

Naval personnel currently have access to several anti-exposure suits, designed for cold air and water exposure, which may be appropriate for shipboard flooding operations. Therefore, the purpose of the present investigation was to evaluate and compare the effectiveness of three anti-exposure suits on preventing decreases in body heat content during intermittent arm exercise in cold water.

Approach.

Ten male subjects were evaluated in waist high cold-water ($7.5^{\circ}\text{C}/45.5^{\circ}\text{F}$) exposure tests consisting of alternating periods of 5 min of rest and 15 min of arm cycle ergometry at 50% of arm peak oxygen uptake as a model of damage control work. The maximum exposure time was 80 min. Each subject completed tests wearing the: 1) Naval fire resistant coverall (CON), 2) CWU-62/P anti-exposure coverall (CWU), 3) Naval cold-weather anti-exposure suit (NCW), and 4) Mustang SurvivalTM anti-exposure suit (MUS).

Physiological measures included rectal temperature (T_{re}), and skin temperatures from the right upper chest (T_{ch}), right upper arm (T_{ar}), right index finger (T_{fi}), right midlateral thigh (T_{th}), right midlateral calf (T_{ca}), and right large toe (T_{to}), as well as heart rate, blood pressure, oxygen uptake, cardiac output, and arterial oxygen percent saturation. The effect of suit type on the dependent measures was examined using repeated measures analysis of variance and covariance.

Results.

Subjects were able to work significantly ($p < 0.05$) longer in CWU and MUS than CON. Differences in stay time between CWU, NCW, and MUS were nonsignificant, as were the differences between NCW and CON.

There were no significant differences in T_{re} across time among suits. All upper body skin temperatures, except for T_{fi} of CON, increased and remained elevated throughout the test. The end stay time T_{ch} and T_{fi} of subjects wearing CWU, NCW, and MUS were significantly higher

than when wearing CON. The T_{ar} for subjects wearing NCW and MUS were significantly higher than for subjects wearing CON. All lower body skin temperatures decreased from immersion to the end of the test. Final in water T_{th} for subjects wearing CWU was significantly higher than while wearing CON, NCW, and MUS. In addition, the T_{th} for subjects wearing NCW was significantly higher than while wearing CON. For subjects wearing CWU and NCW, T_{ca} values were significantly higher than while wearing either CON and MUS. No significant differences were found for T_{to} among suits.

The slopes of the decreases in T_{th} and T_{to} over the first 15 min of the test for CWU were significantly smaller than CON, NCW, and MUS. There were no significant differences in the slope of T_{ca} .

Time integrals for T_{th} and T_{ca} for subjects wearing CWU, NCW, and MUS were significantly greater than while wearing CON. Additionally, the differences in the integrated T_{th} values between subjects wearing CWU and NCW as well as the differences in T_{ca} integral for subjects wearing CWU, NCW, and MUS were significant. The integral for T_{to} for subjects wearing CWU was significantly greater than while wearing CON.

Conclusion.

CWU provided the best protection from decreases in body temperatures during intermittent exercise in cold water. Its impermeable design, in contrast to NCW and MUS, was thought to be a key factor in its effectiveness. These findings may aid in the future development of anti-exposure suits designed specifically for shipboard flooding operations.

INTRODUCTION

Shipboard flooding may arise as a result of breakage of valves and pipes, leakage of bulkheads, and mechanical failures due to fire, explosions, sabotage, mismanagement of the ballast, and breaches to the ship's hull from collision and battle damage. These situations often require damage control personnel to work in ocean water as cold as 0°C (32°F). It is well known that the health of individuals can be seriously affected by work in and exposure to cold water. (Hayward, 1984; Hayward & Eckerson, 1984).

One of the most serious hazards of cold-water immersion is heat loss (Keatinge, 1969). With a thermal conductivity that is 20 to 25 times that of air, cold water quickly absorbs most of the heat which reaches the skin (McArdle et al., 1984a; Nadel, 1984). During exposure to cold water, maintenance of body heat depends on the amount of heat production from physical work, involuntary shivering, amount of individual body fat, and magnitude of cutaneous vasoconstriction (Toner et al., 1989). However, during prolonged cold-water exposure, these factors are unable to protect an individual against excessive decreases in body temperature. When rectal temperature drops below 35.5°C (95°F) a state of hypothermia is reached which can eventually lead to death (Hayward, 1984; Horvath, 1982).

Damage control personnel normally perform shipboard flooding operations dressed in dungarees or engineering coveralls. However, because of their low amount of insulation, these garments may not be adequate for cold-water exposure. Thus, the identification of protective ensembles for work in cold water is of interest to shipboard damage control personnel (Kaufman & Dejneka, 1985; Steinman et al., 1987; White & Roth, 1979).

Naval personnel currently have access to several anti-exposure suits, designed for cold air and water exposure, which may be appropriate for shipboard flooding operations. These are the CWU-62/P (CWU), the naval cold weather (NCW), and the Mustang Survival™ (MUS) anti-exposure suits. The CWU is an anti-exposure coverall worn by Naval pilots for protection from hypothermia during exposure to ocean waters below 10°C (50°F). The NCW is an anti-exposure suit designed to protect topside personnel on submarines and surface ships from wet, cold-weather conditions. The MUS is commercially available for use in boating activities as an anti-exposure suit and personal flotation device. However, at this time no studies have determined the effectiveness of these garments to minimize decreases in body temperatures during cold water exposure. Therefore, the purpose of the present investigation was to evaluate and compare the effectiveness of three anti-exposure suits, designed for purposes other than shipboard flooding, on preventing decreases in body temperatures during intermittent arm exercise in cold water.

METHODS

The protocol and procedures used in this study were approved by the Committee for the Protection of Human Subjects of the Naval Health Research Center.

Subjects.

Ten males served as subjects. The physical characteristics of the subjects were 28.0 ± 6.5 years, 174.8 ± 5.1 cm, 76.8 ± 13.4 kg, and $16.2 \pm 5.2\%$ body fat. The average peak oxygen uptake from a maximal arm cycle ergometer test was 28.3 ± 6.0 ml·kg⁻¹·min⁻¹. All subjects were trained in shipboard damage control operations.

Medical screening.

Each subject gave their informed consent prior to participation in testing. All subjects underwent medical screening which included a medical history questionnaire, body composition assessment, resting 12-lead electrocardiogram (ECG), and a maximal arm cycle ergometer test. Body surface area (m²) was calculated according to the height and weight regression equation of DuBois (Carpenter, 1964). A U.S. Navy regression equation was used to calculate percent body fat using height and circumference measures of the neck and abdomen (Hodgdon & Beckett, 1984).

Incremental arm cycle ergometer test.

All subjects completed an incremental arm cycle ergometer test to volitional exhaustion (Franklin, 1985). Oxygen uptake ($\dot{V}O_2$) was measured using open circuit spirometry and heart rate (HR) was monitored by 12-lead ECG. ECG electrodes were placed on each subject's chest in the Mason-Liker configuration. Two electrodes were placed on the upper chest near the shoulders (infraclavicular fossa), and two others slightly above the waist at the base of the legs. Six electrodes (V_1 - V_6) were also placed on the chest in the precordial position around the lower inside border of the left chest. Resting ECGs and blood pressure (BP) were taken in the supine, seated, and standing positions. BP was measured by auscultation prior to exercise and during recovery until resumption of pretest resting values.

Experimental procedures.

All subjects performed four cold-water exposure tests. These tests were administered a week apart in random order. During these tests the subjects wore the following four ensembles:

- 1.) Naval fire resistant cotton coveralls (Contract #8405-01-204-5403), safety boots, and no gloves (CON);

- 2.) CWU-62/P anti-exposure coverall (Contract #NOO383-86-C-9160), fire resistant coveralls, safety boots, and firefighter gloves (CWU);
- 3.) Naval cold-weather anti-exposure suit (Contract #DLA100-87-C-0671), dungarees, safety boots, and firefighter gloves (NCW);
- 4.) Mustang Survival™ anti-exposure suit (Model MS2175), dungarees, cold-weather boots (Contract #DLA100-81-C-2269), and firefighter gloves (MUS).

The CWU, NCW, and MUS were designed for exposure to both cold air and water. The CWU is composed of inner and outer layers of fire resistant Nomex laminated to a center layer of GORE-TEX® material. It is equipped with natural rubber neck and wrist seals, waterproof zippers, and permanently attached rubber socks making it impermeable to water. The NCW and MUS are made of a coated nylon outershell with an inner layer of expanded polyvinyl chloride (PVC) foam. Both the NCW and MUS were designed to trap and restrict water flow within the layer of insulative foam. Neither the NCW or MUS had neck or wrist seals, waterproof zippers, or attached socks.

The subjects were instructed to abstain from exercise for 24 hr prior to the test and to consume at least two glasses (16 oz.) of water the night before the test. Hydration status was determined by measuring the specific gravity of urine samples obtained prior to the test.

The test protocol consisted of four alternating periods of 5 min of rest and 15 min of exercise. The maximum allowable cold-water exposure time was 80 min. During the exercise periods, subjects performed arm cycle ergometry to simulate damage control work. The exercise intensity was set at 50% of arm peak oxygen uptake. Subjects stood immersed to the waist in a SwimEx™ SWXF-400 Aquatic Exercise Machine (SwimEx Systems, Inc., Warren, RI). The water temperature averaged 7.5°C (45.5°F) and the water flow rate was set at 3 mph. The room air temperature and relative humidity (rh) averaged 25°C (77°F) and 83%, respectively.

The test was terminated when the subject reached endpoint criteria based on signs or symptoms of hypothermia or hyperthermia, or when the subject reached volitional fatigue. The termination criteria for hypothermia were a decrease in rectal temperature to less than 35.5°C (95°F), or a decrease in finger or toe temperatures to 5°C (41°F), or less than 10°C (50°F) for 15 min. The termination criteria for hyperthermia was an increase in rectal temperature to more than 39.5°C (103.1°F). The termination criteria for exercise responses was a HR above 90% of maximum for 5 min during exercise, a HR above 80% of maximum for 5 min during rest, a HR above 210 bpm at any time, a systolic BP above 200 mmHg, a diastolic BP above 120 mmHg, nausea, dizziness, or disorientation.

Measurements.

Prior to the test, subjects inserted a rectal thermistor to a depth of 20 cm in the rectum for the measurement of rectal temperature (T_{re}). Skin temperatures were measured using thermistors placed at the right upper chest (T_{ch}), right upper arm (T_{ar}), right index finger (T_{fi}), right midlateral thigh (T_{th}), right midlateral calf (T_{ca}), and right large toe (T_{to}). Three ECG electrodes were placed on the chest to monitor HR. T_{re} , T_{ch} , T_{ar} , T_{fi} , T_{th} , T_{ca} , T_{to} , and HR were recorded at 1-min intervals by a portable Squirrel data logger (Science/Electronics, Miamisburg, OH) worn outside the ensemble. HR was also recorded by a Polar Heartwatch System (Polar, USA, Inc., Stamford, CT). BP was measured by auscultation using a Colin STBP-780 stress test blood pressure monitor (Colin Medical Instruments Corp., South Plainfield, NJ).

$\dot{V}O_2$ was measured during the rest and exercise periods by open circuit spirometry. These measurements were not taken at every interval and were taken more often during exercise than rest periods. Pulmonary minute ventilation ($\dot{V}E$) was measured using a timed volume collection in 120 L Tissot tank. Cardiac output (\dot{Q}_c) was determined by the indirect Fick method (Jones & Campbell, 1982). End-tidal partial pressure of carbon dioxide was used to estimate venous carbon dioxide content, while the equilibrium carbon dioxide percentage attained after rebreathing was used to estimate arterial carbon dioxide content. The percentage of oxygen in arterial blood was measured from the ear lobe using a noninvasive pulse oximeter.

At the end of each rest and exercise period, subjects were asked for ratings of perceived exertion (RPE) and thermal sensation (TS). RPE was determined using the Borg 15-point scale (6 to 20) (Borg, 1982). The RPE scale ranged from 6 (very, very light) to 20 (very, very hard). A 9-point scale (0 to 8) was used for TS (Young et al., 1987). The TS scale ranged from 0 to 8 with a 4 representing "comfortable" and a 0 and 8 representing "unbearably cold" and "unbearably hot" respectively. TS was reported for the head, chest, hand, thigh, calf, and foot.

Total-body sweat loss was calculated as the difference in pretest and posttest body weight after adjustment of the posttest weight for urine output and water intake. Subjects were provided with water ad libitum during the rest periods. Fluid balance was calculated as water intake minus urine output and sweat loss.

Statistical analysis.

The SAS® System software (SAS Institute Inc., Cary, NC) was used for statistical analysis of the data. Stay time, lower body temperature integrals, metabolic, cardiovascular, RPE, TS,

and fluid dynamics data were analyzed by repeated measures analysis of variance (AVOVA). Stay time was defined as the total time of cold-water exposure. The lower body temperature integrals reflected the sum of temperature values taken every minute during stay time. End stay time T_{re} , T_{ch} , T_{ar} , and T_{fi} were analyzed by repeated measures analysis of covariance (ANCOVA) using preexposure values as covariates.

Due to temperature fluctuations in the lower body caused by cold-induced vasodilation, the absolute low T_{th} , T_{ca} , and T_{to} near the end of stay time were examined rather than the true end stay time temperatures. Slopes of the decreases in T_{th} , T_{ca} , and T_{to} were computed over the first 15 min of cold-water exposure. The absolute low temperatures and slopes were also analyzed by repeated measures ANCOVA using preexposure values as covariates. Post hoc analyses were performed by Least Squares Means tests to evaluate significant differences among suits. The significance level was set at $p < 0.05$.

RESULTS

Stay time.

Subjects wearing CWU and MUS had significantly ($p < 0.05$) longer stay times than while wearing CON (Table 1 and Figure 1). Differences in stay time between subjects wearing CWU, NCW, and MUS were nonsignificant, as were the differences between subjects wearing NCW and CON.

Table 1. Comparison of stay times. (n = 10)

Variable	CON	CWU	NCW	MUS	Comparison
Stay time (min)	60.9 ± 19.9	77.9 ± 5.0	72.5 ± 12.3	76.4 ± 6.2	CWU > 1* MUS > 1*

* $p < 0.05$

Values represent means ± SD

Metabolic, cardiovascular, and fluid dynamics responses.

No significant differences were found among suits with respect to either metabolic or cardiovascular responses. Thus, the data from all four suits were combined. Resting $\dot{V}O_2$ was 0.52 ± 0.13 L·min⁻¹, and the resting $\dot{V}CO_2$ was 0.65 ± 0.16 L·min⁻¹. The resting respiratory exchange ratio (RER) was 1.25 ± 0.18 and estimated energy expenditure was 194 ± 48 watts.

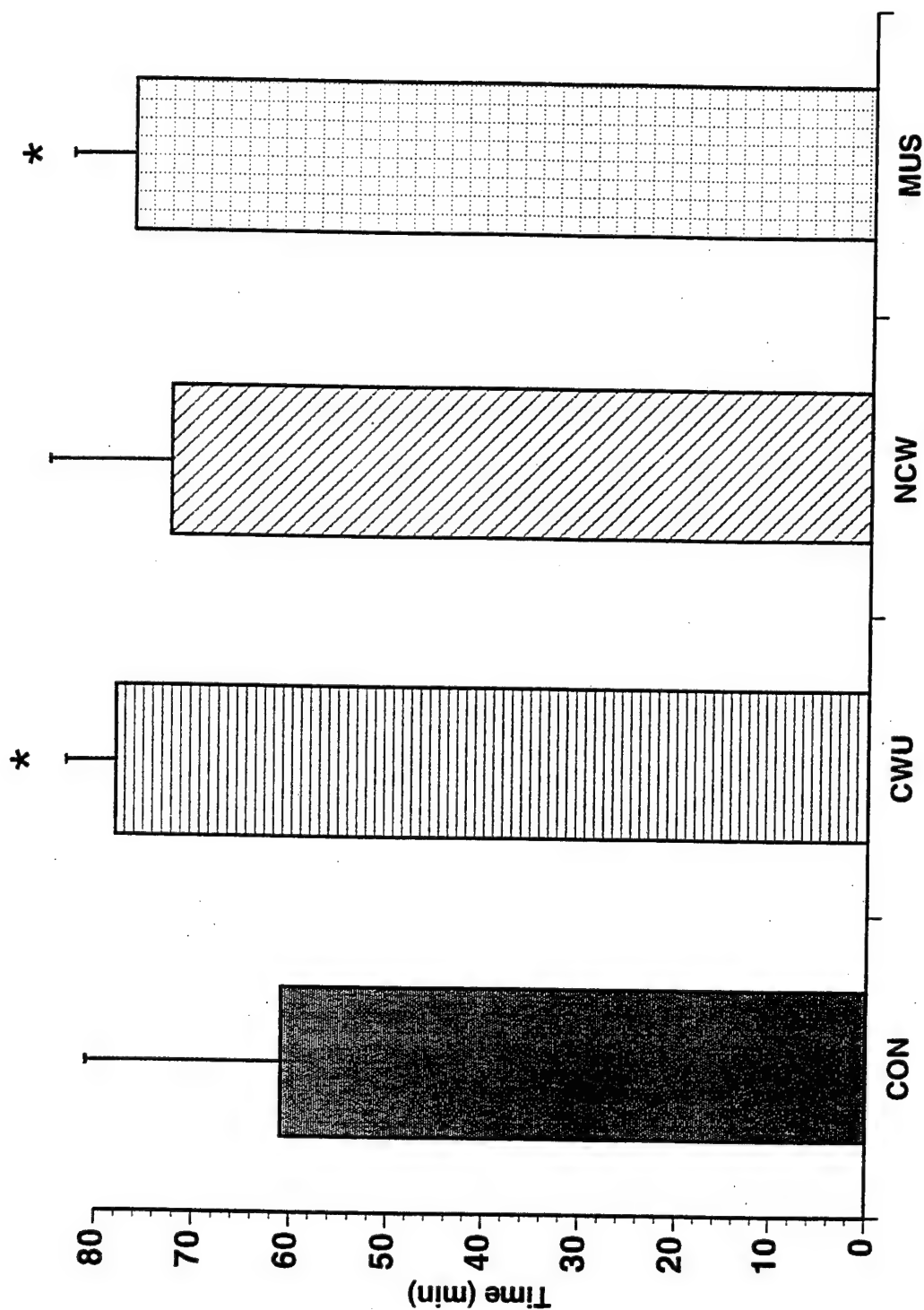


Figure 1. Comparison of mean stay times (\pm SD) for anti-exposure suits. Stay times for subjects wearing CWU and MUS were significantly longer than CON. Differences in stay times among CWU, NCW, and MUS were nonsignificant.

Resting $\dot{V}E$ averaged $21.6 \pm 6.0 \text{ L}\cdot\text{min}^{-1}$. Exercising $\dot{V}O_2$ was $1.41 \pm 0.28 \text{ L}\cdot\text{min}^{-1}$, and the exercising $\dot{V}CO_2$ was $1.35 \pm 0.25 \text{ L}\cdot\text{min}^{-1}$. The exercise RER was 0.96 ± 0.09 and the energy expenditure of 492 ± 95 watts. Exercising $\dot{V}E$ averaged $36.7 \pm 5.5 \text{ L}\cdot\text{min}^{-1}$.

Upon entry into cold water, all subjects showed a rapid increase in HR to a range of 90 to 110 bpm (Figure 2). The average resting HR was 94 ± 8 bpm, while the average exercising HR was 117 ± 7 bpm. No significant differences were found among the suits for either resting or exercising HR. The average resting \dot{Q}_c was $6.2 \pm 1.4 \text{ L}\cdot\text{min}^{-1}$, and the average resting mean arterial pressure was 88 ± 10 mmHg. These yielded a resting total peripheral resistance of $14 \pm 4 \text{ mmHg}\cdot\text{L}^{-1}\cdot\text{min}^{-1}$. The average exercising \dot{Q}_c was $10.3 \pm 2.0 \text{ L}\cdot\text{min}^{-1}$, and the average exercising mean arterial pressure was 87 ± 10 mmHg, yielding an exercising total peripheral resistance of $8 \pm 2 \text{ mmHg}\cdot\text{L}^{-1}\cdot\text{min}^{-1}$. Stroke volume increased from an average resting value of $68 \pm 14 \text{ ml}\cdot\text{beat}^{-1}$ to $84 \pm 15 \text{ ml}\cdot\text{beat}^{-1}$ at exercise. From rest to exercise systolic BP rose from 124 ± 13 mmHg to 132 ± 14 mmHg, while diastolic BP dropped from 71 ± 10 mmHg to 65 ± 10 mmHg. Arterial oxygen percentage did not change from rest, $94.3 \pm 2.1\%$, to exercise, $94.5 \pm 2.3\%$.

There was no significant differences among suits for water intake, urine output, sweat loss, or fluid balance. Water intake for all four suits averaged 372 ± 297 ml, while urine output averaged 105 ± 110 ml. In addition, the average sweat loss was 394 ± 263 ml, while the fluid balance averaged -127 ± 271 ml.

Ratings of perceived exertion and thermal sensation.

There were no significant differences in RPE or TS among suits. Thus, the data for all four suits were combined and are summarized in Table 2. The average resting RPE was 8.6 ± 2.4 (very light), while the average exercising RPE was 13.5 ± 1.5 (somewhat hard).

The upper body TS values (head, chest, and hand) rose only slightly above "comfortable" for the duration of the test. TS values of the immersed lower body areas (thigh, calf, and foot) dropped sharply to "cold" within the first 5 min and remained at this level throughout the test. TS for the foot was the lowest followed by the calf and thigh.

End stay time and absolute low temperatures.

Table 3 summarizes the results of the analysis of end stay time and absolute low temperatures. There were no significant differences in T_{re} among suits. A composite of all four suits shows only a slight rise in T_{re} which levelled off by the end of the test (Figure 3).

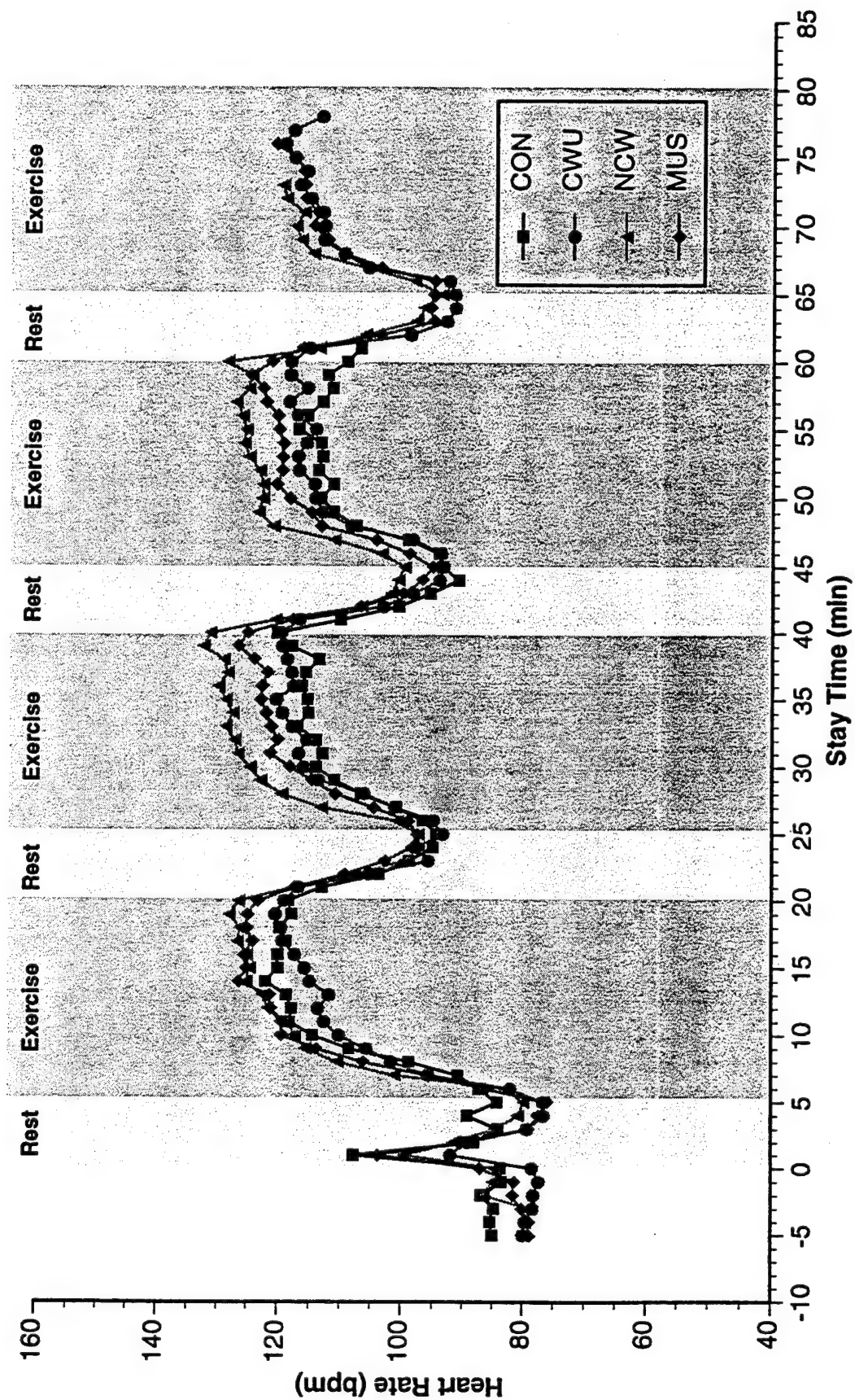


Figure 2. Comparison of mean heart rates among anti-exposure suits. Differences among the suits were nonsignificant.

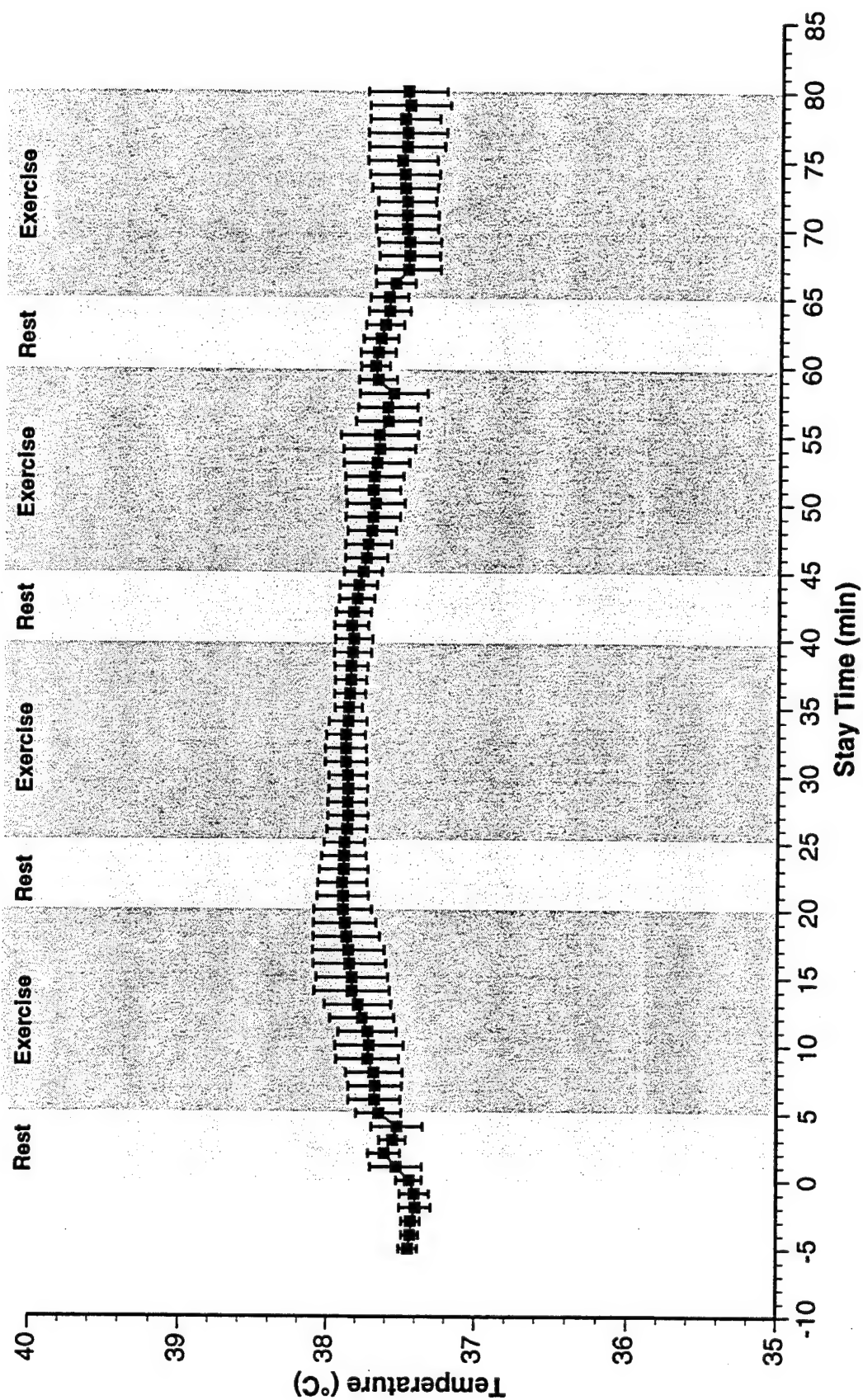


Figure 3. Composite mean rectal temperatures (\pm SD) for anti-exposure suits. Differences among the suits were nonsignificant.

All upper body skin temperatures, except for T_{re} for subjects wearing CON, increased and remained elevated throughout the test. The T_{ch} for subjects wearing CWU, NCW, and MUS were significantly higher than while wearing CON (Figure 4). When subjects wore CON, CWU, NCW and MUS, T_{ch} rose through the end of the first exercise period, and then levelled off for the remainder of the test. The T_{ar} for subjects wearing NCW and MUS were significantly higher than while wearing CON (Figure 5). The T_{re} for subjects wearing CWU, NCW, and MUS were significantly higher than while wearing CON (Figure 6). T_{re} dropped initially and then rose after the first exercise period, except for CON which continued to decrease slowly through the end of the test. T_{re} for all suits increased during the rest periods and decreased during the exercise periods.

Table 2. RPE and TS during rest and exercise. (n = 10).

Variable	Rest	Exercise
RPE	8.6 \pm 2.4	13.5 \pm 1.5
TS Head	4.5 \pm 0.5	4.8 \pm 0.7
TS Chest	4.4 \pm 0.6	4.7 \pm 0.8
TS Hand	4.4 \pm 0.6	4.6 \pm 0.8
TS Thigh	2.9 \pm 0.7	2.9 \pm 0.7
TS Calf	2.6 \pm 0.8	2.5 \pm 0.8
TS Feet	2.2 \pm 0.9	2.1 \pm 0.9

Values represent means \pm SD

All lower body skin temperatures decreased from immersion to the end of the test. The T_{th} for subjects wearing CWU was significantly higher than while wearing CON, NCW, and MUS. In addition, the T_{th} for subjects wearing NCW was significantly higher than while wearing CON (Figure 7). T_{th} for subjects wearing NCW and MUS showed a similar trend of warming during rest and cooling during exercise periods that was noted with T_{re} . Subjects wearing CWU and NCW had significantly higher T_{ca} values than while wearing either CON and MUS (Figure 8). Although the more insulative cold-weather boots were worn with the MUS, no significant differences were found in T_{to} among suits (Figure 9).

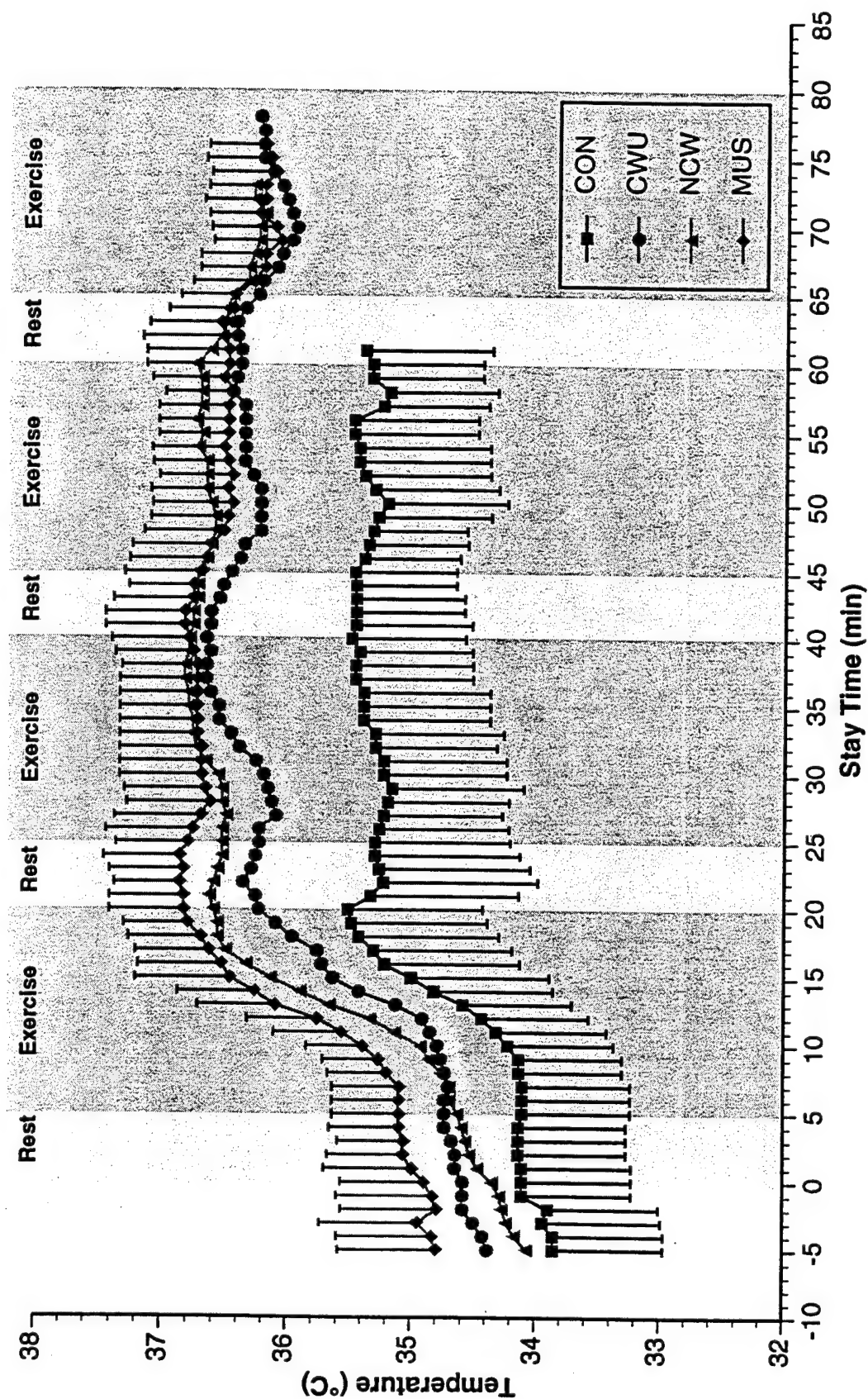


Figure 4. Comparison of mean chest skin temperatures (\pm SD) among anti-exposure suits. End stay time temperatures of CWU, NCW, and MUS were significantly higher than CON.

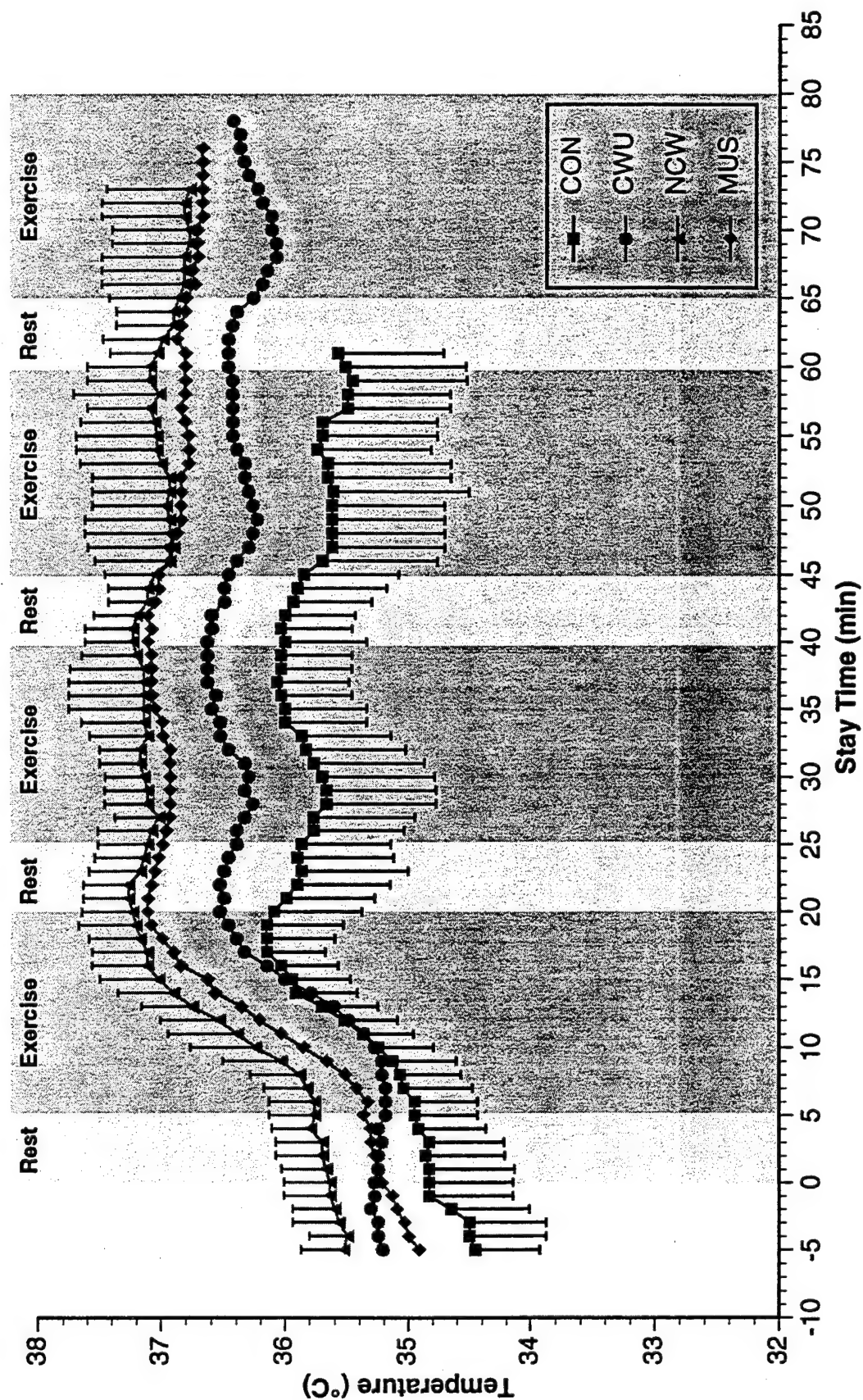


Figure 5. Comparison of mean arm skin temperatures (\pm SD) among anti-exposure suits. End stay time temperatures of NCW and MUS were significantly higher than CON.

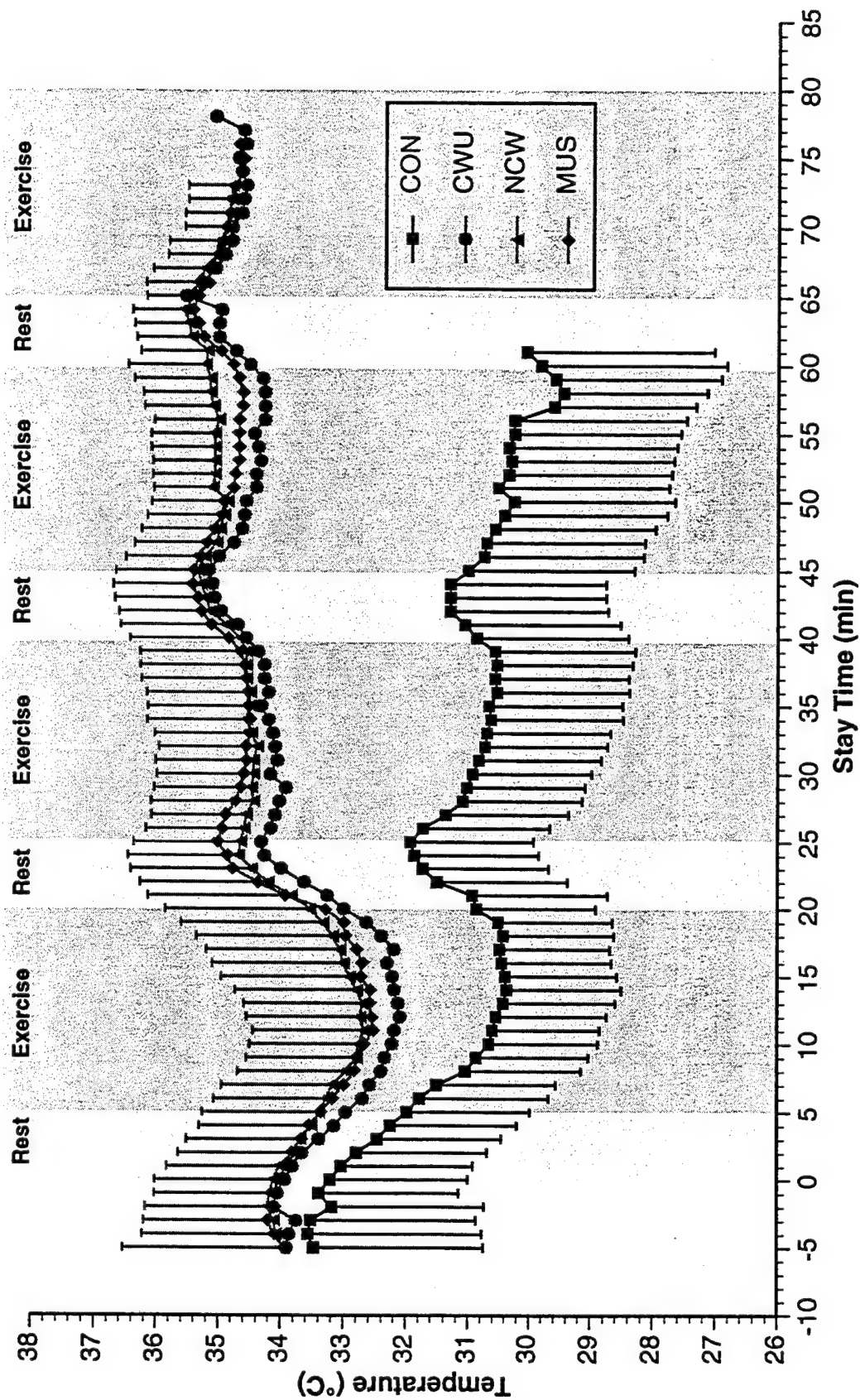


Figure 6. Comparison of mean finger skin temperatures (\pm SD) among anti-exposure suits. End stay time temperatures of CWU, NCW, and MUS were significantly higher than CON.

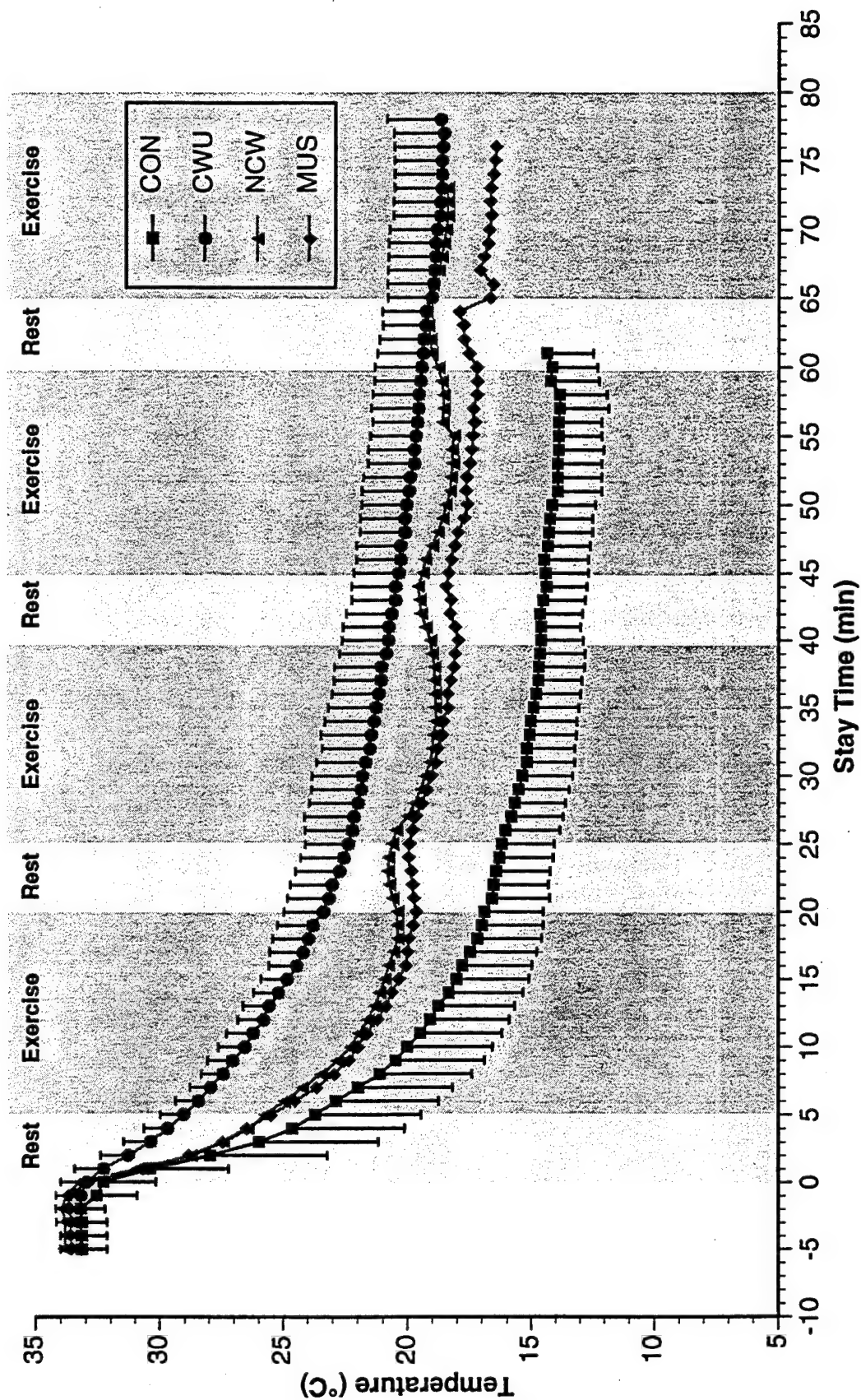


Figure 7. Comparison of mean thigh skin temperatures (\pm SD) among anti-exposure suits. Slope of temperature decline of CWU in minutes -1 to 15 was significantly smaller than CON, NCW, and MUS. Absolute low temperature of CWU was significantly higher than CON, NCW, and MUS and NCW was significantly higher than CON.

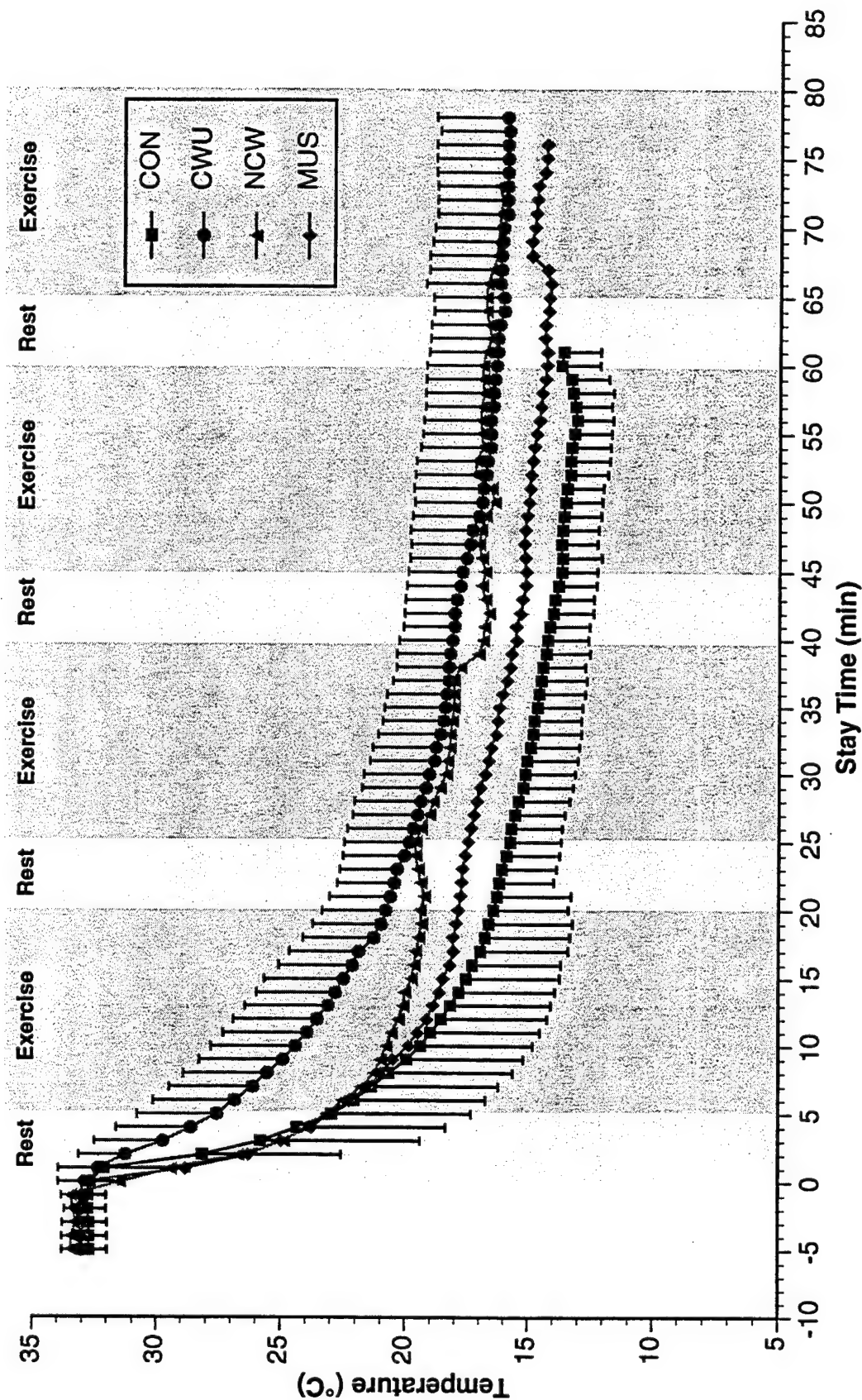


Figure 8. Comparison of mean calf skin temperatures (\pm SD) among anti-exposure suits. No significant differences in the slope of temperature decline in minutes -1 to 15. Absolute low temperatures of CWU and NCW were significantly higher than CON and MUS.

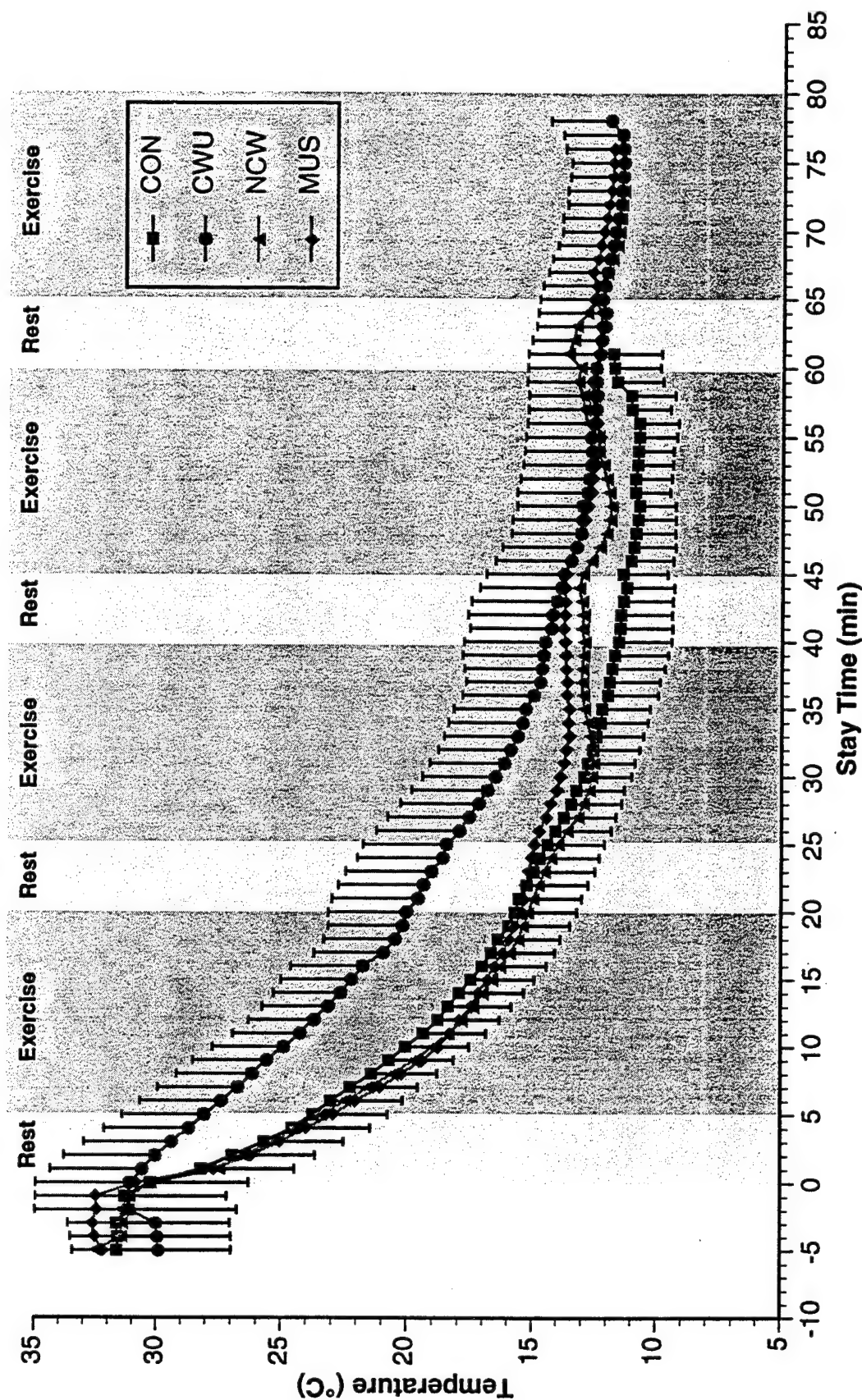


Figure 9. Comparison of mean toe skin temperatures (\pm SD) among anti-exposure suits. Slope of temperature decline of CWU in minutes -1 to 15 was significantly smaller than CON, NCW, and MUS. No significant difference in absolute low temperature among suits.

Lower body temperature slopes.

The slopes of the declines in T_{th} and T_{to} for the CWU were significantly smaller than CON, NCW, and MUS (Table 4). There were no significant differences in the slope of T_{ca} .

Lower body temperature integrals.

Results of the analysis of lower body temperature integrals are presented in Table 5. The integrals of T_{th} and T_{ca} for subjects wearing CWU, NCW, and MUS were significantly greater than while wearing CON. Additionally, the differences in T_{th} integrals between subjects wearing CWU and NCW as well as the differences in T_{ca} integrals between subjects wearing CWU and both NCW and MUS were significant. The T_{to} integrals for subjects wearing CWU was significantly greater than while wearing CON.

Table 3. Comparison of end stay time body temperatures ($^{\circ}\text{C}$). (n = 10).

Variable	CON	CWU	NCW	MUS	Comparison
T_{re}	37.38 § ± 0.24	37.52 ± 0.23	37.75 ± 0.23	37.36 ± 0.23	N.S.
T_{ch}	35.28 ± 0.21	36.29 § ± 0.22	36.50 ± 0.21	36.28 § ± 0.23	CWU, NCW, MUS > CON*
T_{ar}	35.81 ± 0.26	36.44 § ± 0.25	36.94 ± 0.26	36.74 ± 0.23	NCW, MUS > CON*
T_{fi}	30.33 ± 0.63	34.37 ± 0.62	34.65 ± 0.62	34.93 ± 0.62	CWU, NCW, MUS > CON*
T_{th}	14.16 ± 0.61	19.34 § ± 0.68	16.96 ± 0.61	15.79 ± 0.63	CWU > CON, NCW, MUS* NCW > CON*
T_{ca}	12.40 ± 0.57	16.05 § ± 0.61	15.40 ± 0.57	12.75 ± 0.57	CWU, NCW > CON, MUS*
T_{to}	10.02 ± 0.91	10.85 ± 0.90	10.24 § ± 0.97	11.22 ± 0.94	N.S.

* $p < 0.05$

§ n = 9

Values represent means ± SE

Table 4. Comparison of lower body skin temperature slopes from minutes -1 to 15 of cold-water exposure (n = 10).

Variable	CON	CWU	NCW	MUS	Comparison
T _{th}	-0.017 ± 0.0015	-0.007 ± 0.0015	-0.013 ± 0.0014	-0.014 § ± 0.0014	CWU < CON, NCW, MUS*
T _{ca}	-0.016 ± 0.0017	-0.014 ± 0.0016	-0.013 ± 0.0018	-0.015 § ± 0.0018	N.S.
T _{to}	-0.016 ± 0.0017	-0.010 ± 0.0018	-0.019 ± 0.0017	-0.018 ± 0.0016	CWU < CON, NCW, MUS*

* p < 0.05

§ n = 9

Values represent means ± SE

Table 5. Comparison of lower body skin temperature integrals during stay time cold-water exposure. (n = 10).

Variable	CON	CWU §	NCW	MUS	Comparison
T _{th}	1012 ± 285	1741 ± 144	1451 ± 252	1506 ± 224	CWU, NCW, MUS > CON* CWU > NCW*
T _{ca}	948 ± 325	1519 ± 225	1298 ± 273	1222 ± 341	CWU, NCW, MUS > CON* CWU > NCW, MUS*
T _{to}	908 ± 339	1317 ± 245	1065 ± 287	1174 ± 199	CWU > CON*

* p < 0.05

§ n = 9

Values represent means ± SD

DISCUSSION

The purpose of the present investigation was to evaluate and compare the effectiveness of three anti-exposure suits on preventing decreases in body temperatures during intermittent arm exercise in cold water.

Metabolic responses.

The most immediate response to cold-water immersion is a rapid rise in pulmonary ventilation, initiated by cold receptors in the skin (Cooper et al., 1976; Keatinge & Nadel, 1965). In the current study, the resting \dot{V}_E was double the normal resting value and was most likely responsible for the large resting \dot{V}_{CO_2} and RER values. The increase in \dot{V}_E may have been potentiated by a flushing of carbon dioxide from the extracellular fluid volume by hydrostatic pressure created by water immersion (Mekjavic & Bligh, 1989).

The resting metabolic rate (194 ± 48 watts) was nearly double that of normal resting values (106 ± 6 watts) (Hayward et al., 1977). Similar increases in metabolic rate have been documented in previous cold-water immersion studies (Cooper et al., 1976; Hayward et al., 1977; Hayward & Eckerson, 1984). Exercise intensity during cold-water immersion was set at 50% of arm peak oxygen uptake. However, exercising at this intensity in cold water resulted in \dot{V}_{O_2} values which were 64% of arm peak maximum. Although this study did not directly measure shivering, the elevations in resting and exercise energy expenditure are thought to be caused by shivering thermogenesis in an attempt to maintain thermal balance (McArdle et al., 1984b).

Cardiovascular responses.

An increase in hydrostatic pressure due to thermoneutral water immersion to the neck leads to a central shift in blood volume resulting in improved venous return and subsequent increases in end diastolic volume, stroke volume, and \dot{Q}_c (Choukroun & Varene, 1990; Haffor et al., 1991; Svedenhag & Seger, 1992). During cold-water immersion, however, thermal effects can override those of hydrostatic pressure leading to an increase in BP, a slightly lowered HR, and an unchanged \dot{Q}_c (Choukroun & Varene, 1990). In the current study, BP, stroke volume, and \dot{Q}_c were not elevated above normal levels. However, the average resting HR (94 ± 8 bpm) was higher than normal. The lack of cardiovascular change may have been related to the level of immersion. In the current study, subjects were immersed to the waist whereas in previous studies subjects were immersed to the shoulders or neck producing a greater shift in blood volume to the chest region.

Stay time.

The significantly longer stay times wearing CWU and MUS compared to CON indicate that these suits provided the most effective protection for the lower extremities against decreases in skin temperature. Thus, when subjects wore CWU and MUS, stay time were prolonged because these suits minimized the rate of decline in skin temperatures, especially T_{to} .

Core and skin temperature responses.

In the current study, T_{re} was maintained and did not decrease during immersion. Interestingly, subjects sweated on average 394 ml throughout all cold-water exposure tests. This indicate that heat production from arm cycling ergometry more than compensated for heat loss from the legs and feet. However, it is likely that core temperature was also maintained by an increases in vasoconstriction. Additional heat conservation occurred as a function of subcutaneous fat thickness (Nadel, 1984) and by the anti-exposure suits, both of which add insulation to prevent heat loss.

The level of immersion was also thought to be a key factor in the maintenance of T_{re} . During cold-water immersion of the entire body, the greatest heat loss occurs at the lateral thorax, upper chest, and groin (Hayward et al., 1973). Most studies reporting decreases in T_{re} , with or without anti-exposure suits, have exposed these areas of the body to cold water by immersing their subjects to the neck (Hayward, 1984; Hayward & Eckerson, 1984; McArdle et al., 1992; White & Roth, 1979). In the current study, however, subjects were only immersed to the waist thus leaving the lateral thorax and upper chest above the water. Therefore, the heat produced at the torso by shivering and arm exercise was held within the suits rather than being lost to the water by convection.

Unexpectedly, seven cases of rapid increases in T_{re} and three cases of rapid decreases in T_{re} were observed upon cold-water immersion. The average increase in T_{re} was 1.79°C over a 1 to 2-min period. T_{re} then returned to baseline levels within 2 min. These increases in T_{re} were thought to be the result of rapid vasoconstriction in the lower extremities and the resulting flushing of warm blood to the torso. The average decrease in T_{re} was 0.60°C over a 1 to 2-min period followed to a return to baseline within 3 min. These changes cannot be explained. All 10 cases of rapid T_{re} change occurred in subjects wearing the CON, NCW, and MUS in which water made direct contact with the skin. This suggests that water contact with the skin may have led to a greater degree of vasoconstriction.

It is well known that individuals with a greater amount of subcutaneous fat tolerate cold-water exposure much better than lean individuals (Hayward & Keatinge, 1981; Keatinge, 1969; McArdle et al., 1984a). The thicker layer of subcutaneous fat provides an effective barrier against heat loss. However, Toner et al. (1989) demonstrated that dry suits masked differences in heat loss normally seen between fat and lean people. The results of the current study support these findings. Although body fat percentages ranged from 9% to 22%, there were no apparent differences in T_{re} or skin temperatures between lean and fat subjects in any of the suits.

While there were no differences in the upper body skin temperatures (T_{ch} , T_{ar} , and T_{fi}) among the CWU, NCW, and MUS, the immersed lower body skin temperatures (T_{th} , T_{ca} , and T_{lo}) indicate that the CWU provided the most effective protection. The CWU had the highest end stay time temperatures at the thigh and calf. Analysis of slopes and temperature integrals of T_{th} , T_{ca} , and T_{lo} show that the CWU had the slowest rate of temperature decline from min -1 to 15 and the highest overall temperatures.

The skin temperatures of most subjects fluctuated in response to the rest and exercise periods. These responses can be explained by alterations in sympathetic neural activity. Sympathetic neural outflow during exercise leads to vasoconstriction in nonactive skeletal muscle and skin so that oxygen-rich blood can be directed to working muscles (Seals & Victor, 1991). The redirection of blood to the muscles of the chest and arms during arm cycle ergometry led to a slightly delayed increase in T_{ch} and T_{ar} . This was followed by a slight decrease in T_{ch} and T_{ar} during rest periods when blood was redistributed to the periphery. However, T_{fi} showed the opposite trend. During exercise, T_{fi} decreased as blood was drawn to the exercising muscles. The reduction in sympathetic outflow and the subsequent reduction in vasoconstriction during rest allowed T_{fi} to increase.

Lower body skin temperature fluctuations were influenced not only by intermittent sympathetic outflow from exercise, but also by continuous sympathetic outflow created by cold-water immersion (Seals & Victor, 1991). T_{th} of NCW and MUS as well as T_{ca} of NCW responded much like T_{fi} . The combined sympathetic outflow from exercise and cold-water immersion led to decreases in T_{th} and T_{ca} . These skin temperatures increased during rest periods when sympathetic outflow was only mediated by cold-water immersion. The fluctuations in T_{th} and T_{ca} were found only with NCW and MUS in the range of approximately 17°C to 21°C. T_{th} and T_{ca} of CON and T_{ca} of MUS were below this range and may have had vasoconstrictor drives which were already saturated and thus unable to respond to the additional sympathetic outflow from exercise. T_{th} and T_{ca} of CWU fell within the 17°C to 21°C range after 25 to 40 min,

however, no fluctuations were noted. The lack of any fluctuations within this range for the CWU may be related to its slower rate of temperature decline.

Fluctuations in T_{to} were also noted, however, most of these were not related to the rest and exercise periods. These fluctuations were caused by cold-induced vasodilation (CIVD). CIVD occurs primarily in the fingers and toes in response to cold exposure (Keatinge, 1969). It is a protective mechanism which intermittently raises peripheral temperature by overriding the strong vasoconstrictor drive in order to delay cold injury. This is achieved at the expense of increasing heat loss which compromises the body's ability to maintain core temperature. The incidence of CIVD in the current study, however, did not lead to a decrease in T_{re} . CIVD appeared in five separate tests with three different subjects. They involved increases in T_{to} from 1.5°C to 11.4°C and were more prevalent during the second and third exercise sessions (Figure 10). Lewis (1930) and Keatinge (1969) found that the threshold for CIVD with both whole body and local cold-water immersion was 10°C to 12°C. The onset of CIVD in the current study took place between 12°C and 19°C. All five cases of CIVD took place in subjects wearing either the NCW or MUS. As with T_{th} and T_{ca} , T_{to} of NCW and MUS represented the middle range of temperatures which were neither too warm or too cold for the occurrence of CIVD. Two subjects displayed very individual patterns of CIVD (Figure 11). Subject 1 had three to four waves of CIVD which were 20 min in length each. Subject 2, however, only had one elongated CIVD which was 40 to 47 min in length and had the appearance of two or more CIVD waves added together.

The CWU's effectiveness in preventing large decreases in lower body temperatures is thought to be a function of its impermeable design. While the CWU served as a water barrier for the underlying clothing and skin, it provided little or no insulation. Previous studies have found that dry suits are superior to wet suits only if they protect against convective heat loss through the use of insulative foam or air-trapping clothing beneath the suit (Hayward et al., 1978; Hayward, 1984; Steinman et al., 1987). In the current study, the underlying fire-resistant coveralls seemed to provide adequate insulation when immersed to the waist. However, if the level of immersion is higher and covers the torso, additional or more effective insulative layers may be required.

The NCW and MUS were not impermeable to water. These suits are designed to trap and restrict water flow within a layer of insulative foam. Under very calm conditions this trapped water can be warmed by the body to reduce heat loss. However, if this layer is flushed by water movement or physical activity it can lead to a reduction of the suit's insulative capacity (Steinman et al., 1987; Wolff et al., 1985). Although there was little physical movement of the

lower extremities, the current study did involve a 3 mph water current which most likely reduced the effectiveness of the NCW and MUS in maintaining body heat. It is important to point out, however, that both the NCW and MUS provided adequate thermal protection for the lower body and could be used in cold-water immersion to the waist for 30 to 40 min based on the rates of temperature declines.

Ratings of perceived exertion and thermal sensation.

The lack of a significant difference in RPE was not surprising since power output was constant across all suits. Although there were significant differences in skin temperatures, no significant differences were found in TS among suits. Hayward (1984) concluded that the sensation of coldness is peripherally derived. Subjects in this study may have based their TS on T_{re} where there were no significant differences among suits at the end of stay time. Another explanation may be that TS is not a sensitive measure of actual body temperature when the skin is exposed to very cold-water temperatures.

Implications for future suit design.

This study supports Hayward's (1984) conclusion that the most effective clothing for cold-water immersion keeps one dry and provides resistance to conductive heat transfer by the use of insulative foam or air-trapping materials. As mentioned earlier, the CWU provided no insulation itself. Shipboard flooding operations which involve higher levels of immersion may require dry suits which have foam insulation.

The selection of protective clothing for cold-water immersion should not be based solely on insulative capacity (Hayward et al., 1978; Steinman et al., 1987). Other factors which must be considered are heat strain at rest and during work, reduction in mobility, comfort, ease of donning, maintenance, required storage space, and cost. These are all factors which should be evaluated as future shipboard flooding anti-exposure suits are developed.

Conclusions.

In conclusion, the major findings from this study are that: 1) subjects were able to achieve significantly longer cold-water stay times while wearing the CWU and MUS as compared to the CON, 2) the CWU provided the best overall protection against decreases in body temperatures during intermittent arm exercise in waist high cold water, 3) the NCW and MUS could be used in cold-water immersion to the waist for 30 to 40 min, and 4) the effectiveness of the CWU was thought to be due to its impermeable design which reduced conductive heat loss by keeping the subjects and their insulative clothing dry.

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